EFFICIENT USE OF ENERGY UTILIZING HIGH TECHNOLOGY: AN ASSESSMENT OF ENERGY USE IN INDUSTRY AND BUILDINGS - SUMMARY OF FINDINGS

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1.0 Introduction
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As part of its ongoing effort to analyze options for reaching a more sustainable energy future, the World Energy Council (WEC) completed a comprehensive study entitled *Energy for Tomorrow's World* that examined various futures of world energy production and consumption (WEC, 1993). The WEC study found that without any change in current practice, world energy demand in 2020 would be 50-80% higher than 1990 levels. Such demand could place significant strain on the current energy infrastructure and potentially damage world environmental health. More rational use of energy is an important bridge to help all societies transition from today's fossil-fuel-dominated world to a world powered by non-polluting fuels and advanced technologies.

WEC Working Group 3A focused its research on the application of high technology to energy savings in the industrial and buildings sectors. The results of this research, presented in this paper, are drawn from a larger report titled *Efficient Use of Energy Utilizing High Technology: An Assessment of Energy Use in Industry and Buildings* (Levine et al., 1995) that addresses some of the basic questions concerning a sustainable future.

To make this study applicable globally, we divided the countries of the world into three aggregate regions: Organization for Economic Cooperation and Development (OECD) countries, Eastern Europe and the former Soviet Union (EE/FSU), and developing countries. We focus on the efficiency of energy use for the production of material output (e.g. iron and steel production, chemicals production) and for use as energy services in buildings (e.g. lighting, heating, motive power).

Energy consumption measurements are presented in primary values to account for the linkage between end-use activities and the primary energy demand that such activities generate. Losses in the delivery or transformation of energy, particularly for electricity, can be significant.[1] Unless otherwise noted, all fuels have been converted to standard energy equivalent units–tonnes of oil equivalent and joules–in order to allow for ease of comparability.[2]

2.0 Summary of Scenarios, Findings, and Recommendations
2.0 Sommaire de Scénarios, Resultats, et Recommendations

Scenarios

Industrial sector

- *Under a business-as-usual scenario, with continued use of the mix of current technologies and continuing efficiency improvements caused mainly by responses to energy prices and shifts to industrial activities of lower energy intensity, industrial energy use is projected to grow an average of 1.4% per year from 3243 Mtoe (136 EJ) to 4894 Mtoe (205 EJ) between 1990 and 2020.*
- *Under a state-of-the-art scenario, industrial energy use drops by 16% to 4119 Mtoe (173 EJ) in 2020 compared to the business-as-usual scenario.*
- *In an ecologically driven/advanced technology scenario, which forecasts a more rapid uptake of current state-of-the-art technologies and in which some advanced technologies are adopted, industrial energy consumption in 2020 is virtually unchanged from today's value of 3243 Mtoe (136 EJ).*

Buildings sector

- *Under a business-as-usual scenario, with continued use of the mix of current technologies and continuing efficiency improvements caused mainly by responses to energy prices, buildings energy use is projected to grow at an average rate of 2.4% per year from 2464 Mtoe (103 EJ) to 4959 Mtoe (208 EJ) between 1990 and 2020.*
- *Under a state-of-the-art scenario, buildings energy use drops by 18% to 4086 Mtoe (171 EJ) in 2020 compared to the business-as-usual scenario.*
- *In an ecologically-driven/advanced technology scenario, buildings energy consumption in 2020 is 3338 Mtoe (140 EJ), 35% higher than today's level.*

Findings

- *A large number of energy-efficient technologies exist for all industrial subsectors and for buildings.*
- *Advanced electronics and information technology have considerable potential for increasing energy efficiency in industry and buildings. Evolutionary changes include the wide range of control and feedback technologies. More dramatic changes could alter the nature of manufacturing processes, make possible much greater levels of recycling and reuse, and in some cases alter the demand for final products.*
- *Policies with proven track records of success for energy efficiency in buildings in major regions of the industrialized world include appliance energy-efficiency standards, utility demand-side management programs, building energy codes, product energy consumption labeling, government/private partnerships, and organized competitions among manufacturers to produce more energy-efficient products.*

Recommendations

- *Technical assistance and cooperation between industrialized countries and the rest of the world must be greatly expanded for the high energy growth areas in the developing world and the restructured economies in Eastern Europe and the former Soviet Union to achieve significantly higher energy efficiencies. Without such assistance and cooperation, the lower energy paths are not possible because so much of the world's energy growth will be in these regions.*
- *A significant increase in commitment by all countries to energy policies that promote adoption of cost-effective energy technologies is needed to increase the pace of energy efficiency in buildings and industry.*
- *Research and development of energy-efficient technologies, including advanced information technology, is essential if cost-effective energy efficiency is to be brought into the market over the next decades.*
- *A continuing assessment, in increasing depth, of energy efficiency in buildings and industry, following the lines of the present work, is highly desirable. This is especiallyimportant because of the key role that energy efficiency will need to play in building a sustainable energy and environmental future.*

3.0 Summary of World Energy Use
3.0 Sommaire de l'Usage Globale d'Energie

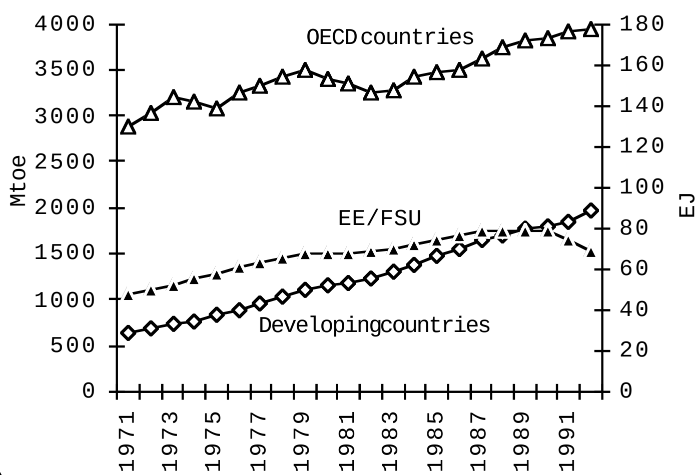
World primary energy consumption grew from 4559 Mtoe (191 EJ) in 1971 to 7420 Mtoe (311 EJ) in 1992, at an average annual growth rate of 2.3% (IEA, 1994a; British Petroleum, 1994). Figure 3-1 shows global primary energy consumption between 1971 and 1992 for three global regions: OECD countries, developing countries, and Eastern Europe and the former Soviet Union (EE/FSU). Detailed information on world primary energy use by sector (industry, buildings, and transport) as well as by region is provided in Table 3-1.

3.1 Primary Energy Use by Region

OECD Countries

OECD countries dominate world energy consumption, accounting for slightly over half of the world total in 1992. Growth in consumption in this region varied over time, as evidenced by the temporary but significant drops in consumption after the two oil price shocks (1973, 1979). Since 1983, however, OECD countries have resumed a steady increase in consumption of 2% annually, and have surpassed the previous peak level that occurred in 1979.

Figure 3-1 Global Primary Energy Consumption by Region, 1971-1992.
Source: IEA, 1994a; British Petroleum, 1994.



Developing Countries

Developing countries consumed about 25% of world primary energy in 1992, and have accounted for much of the growth in world consumption during the past two decades. On average, primary energy consumption in developing countries grew by 5.5% per year between 1971 and 1992. This region is also expected to account for most of the future growth in primary consumption and energy demand. Although traditional fuels are not included in the figure and table due to inadequate data, the vast majority of traditional or non-commercial fuels are consumed in developing countries. Aggregate estimates of biomass fuel consumption based on statistics from the International Energy Agency (IEA) suggest that world biomass consumption has historically been about 8 to 10% of total primary commercial energy consumption, but for some populations in developing countries in Asia and Africa, this percentage can increase to 30 to 50%, representing a significant element of their energy consumption.

EE/FSU

About 20% of the world's primary energy was consumed in the EE/FSU in 1992. The recent comprehensive economic restructuring in the EE/FSU region is reflected in the steep decline in the level of primary consumption after 1988 (Figure 2-1). Average annual energy use declined by 3.8% per year in this region between 1988 and 1992. Many forecasts suggest only modest increases in consumption in the near term (IEA, 1995; U.S. Dept. of Energy, EIA, 1994).

3.2 Primary Energy Use by Sector

The use of energy in an economy can be divided between buildings, industry, and transportation and is shown for 1971, 1980, 1990 and 1992 in Table 3-1. This paper focuses on trends in the industrial and buildings sectors.

Table 3-1. Global Primary Energy Consumption by Sector and Region, 1971-1992.
Source: IEA, 1994a; British Petroleum, 1994.

Region and	1971		1980		1990		1992		Avg. Annual Growth Rate (%)
Sector	Mtoe	EJ	Mtoe	EJ	Mtoe	EJ	Mtoe	EJ	1971-1992
OECD COUNTRIES*									
Industry	1198	50	1354	57	1399	59	1431	60	0.8
Buildings**	1069	45	1295	54	1515	63	1578	66	1.9
Transport	601	25	750	31	917	38	935	39	2.1
Regional Total	2869	120	3399	142	3832	160	3944	165	1.5
EASTERN EUROPE AND THE FORMER SOVIET UNION***									
Industry	626	26	809	34	911	38	758	32	0.9
Buildings**	284	12	481	20	610	26	527	22	3.0
Transport	148	6	200	8	227	10	227	9	2.0
Regional Total	1058	44	1491	62	1748	73	1513	63	1.7
DEVELOPING COUNTRIES*									
Industry	333	14	603	25	932	39	1022	43	5.5
Buildings**	171	7	319	13	545	23	599	25	6.2
Transport	130	5	226	9	313	13	343	14	4.7
Regional Total	633	27	1148	48	1790	75	1964	82	5.5
WORLD									
Industry	2157	90	2767	116	3243	136	3211	134	1.9
Buildings**	1523	64	2095	88	2670	112	2704	113	2.8
Transport	879	37	1177	49	1457	61	1505	63	2.6
Total	4559	191	6038	253	7370	309	7420	311	2.3

* Data from IEA, 1994a. China consumption in 1971 estimated.
** Approximately 10% of the energy use in this sector is for agriculture.
*** Data from British Petroleum, 1994, using sectoral shares based on IEA statistics. Hydroelectricity not converted to its primary equivalent for this region (less than 2% of regional total).

Industrial Sector

The industrial sector consumed 43% of total world primary energy in 1992. Between 1971 and 1992, industrial energy use grew at a rate of 1.9% per year, slightly below world energy demand growth of 2.3% per year. This growth has dropped in recent years, falling to an annual average growth of 0.3% between 1988 and 1992, primarily because of declines in industrial output in the EE/FSU. Energy use in the industrial sector is dominated by OECD countries, which account for 45% of world industrial energy use. Developing countries and the EE/FSU use 32% and 23% of world industrial energy, respectively.

Industrial energy consumption in the OECD increased at an average rate of 0.8% per year between 1971 and 1992 from 1198 Mtoe (50 EJ) to 1431 Mtoe (60 EJ). The share of industrial sector consumption within the OECD has declined slightly, from 42% in 1971 to 36% in 1992. This decline partly reflects the transition toward a less energy-intensive manufacturing base, as well as the continued growth in transportation demand, resulting in large part from the rising importance of personal mobility in passenger transport use (Bekkeheien et al., 1995).

In 1992, the industrial sector accounted for slightly more than 50% of total primary energy demand in both the developing countries and the EE/FSU. The relative share of the industrial sector varies greatly over time and among different countries. Some economies that are experiencing continued expansion in heavy energy-intensive industry, such as China and India, show relatively unchanging shares of industrial energy use, while in other countries, such as Thailand and Mexico, the share and/or growth of the transportation sector dominate (Sathaye and Meyers, 1991). Industrial energy use grew at a rapid annual average of 5.5% in developing countries between 1971 and 1992. Average annual growth in industrial energy use was only 0.9% in the EE/FSU between 1971 and 1992, with industrial energy consumption declines of 4.4% per year between 1988 and 1992 in this region.

Buildings Sector

Approximately 36% of world primary energy is consumed by commercial and residential buildings. Energy use in this sector grew at an average annual rate of 2.8% between 1971 and 1992.

In 1992, OECD buildings consumed 58% of total world buildings energy use, followed by developing countries which consumed 22% and the EE/FSU which consumed 20%. Average annual growth rates in buildings sector energy consumption between 1971 and 1992 were slowest in the OECD (1.9%) and much more rapid in the EE/FSU (3.0%) and developing countries (6.2%) Growth in buildings energy use in developing countries has slowed recently, dropping to 4.0% per year since 1988. The average decline since 1988 in the EE/FSU has been 3.8% per year.

Within developing countries the relative share of buildings energy consumption has increased from about 25% of sectoral energy consumption in 1971 to about 30% of consumption in 1992. Considering the continued demand for housing and the expansion of the service economy in many developing countries, this share is expected to rise in the future.

3.3 Factors Affecting Energy Use

The main factors affecting energy growth in an economy include the energy consumed per unit of economic growth, the size and structure of the economy, and the rate of population growth. If an economy is growing rapidly or population growth is high, then the level of energy demanded will rise commensurately, assuming there is no change in the level of energy demanded per unit of economic output. This is the case with many developing countries, in which economic growth and the expansion of population is rapidly overtaking efficiency improvements within the economy.

The amount of energy consumed per unit of economic growth is affected by how efficiently energy is used to provide energy services in an economy. Shifts in the structure of the economy, in which the overall level of energy services required to produce additional economic output changes, also influence energy use.

All else being equal, reducing economic or population growth will also lead to reductions in energy demand. Reducing population growth will, over the long term, have a profound effect on energy demand. However, most of the impacts of changes in policies affecting population growth will be seen beyond the time horizon for this study (2020). In the near and medium term (1995 to 2020), the most effective and feasible policies for restraining energy growth involve improving the use of energy, and to a lesser extent, encouraging the shift to a less energy-intensive economic structure.

3.4 Measuring Efficiency: Aggregate and Sectoral Energy Intensity Comparisons

A key element in energy efficiency analysis is determination of baseline energy use from which to measure future consumption. An assessment of historical factors affecting energy use and efficiency provides a useful foundation for understanding what can be done in the future.

Aggregate Energy Intensity Comparisons

There are striking differences between energy use relative to gross domestic product (GDP) and population changes in OECD and developing countries (the EE/FSU is not included in this comparison since measures of economic output in this region are difficult to interpret). In OECD countries, GDP growth has outpaced energy use (and population growth) since the oil price shocks in the early 1970s. In contrast, energy growth has outpaced GDP growth in many developing country regions. An important exception is China where energy consumption has grown much more slowly than GDP since 1980 (see Figure 3-2). The dramatic growth rates in both energy use and GDP growth in many regions of the developing world are expected to continue. A recent study for the World Bank predicted Asian developing country energy demand to consume nearly 40% of total global demand by 2005 (Ishiguro and Akiyama, 1994). Understanding the causes and sources of such tremendous expansion will help governments and policy makers confront the prospect of restraining growth in the future.

Sectoral Energy Intensity Comparisons

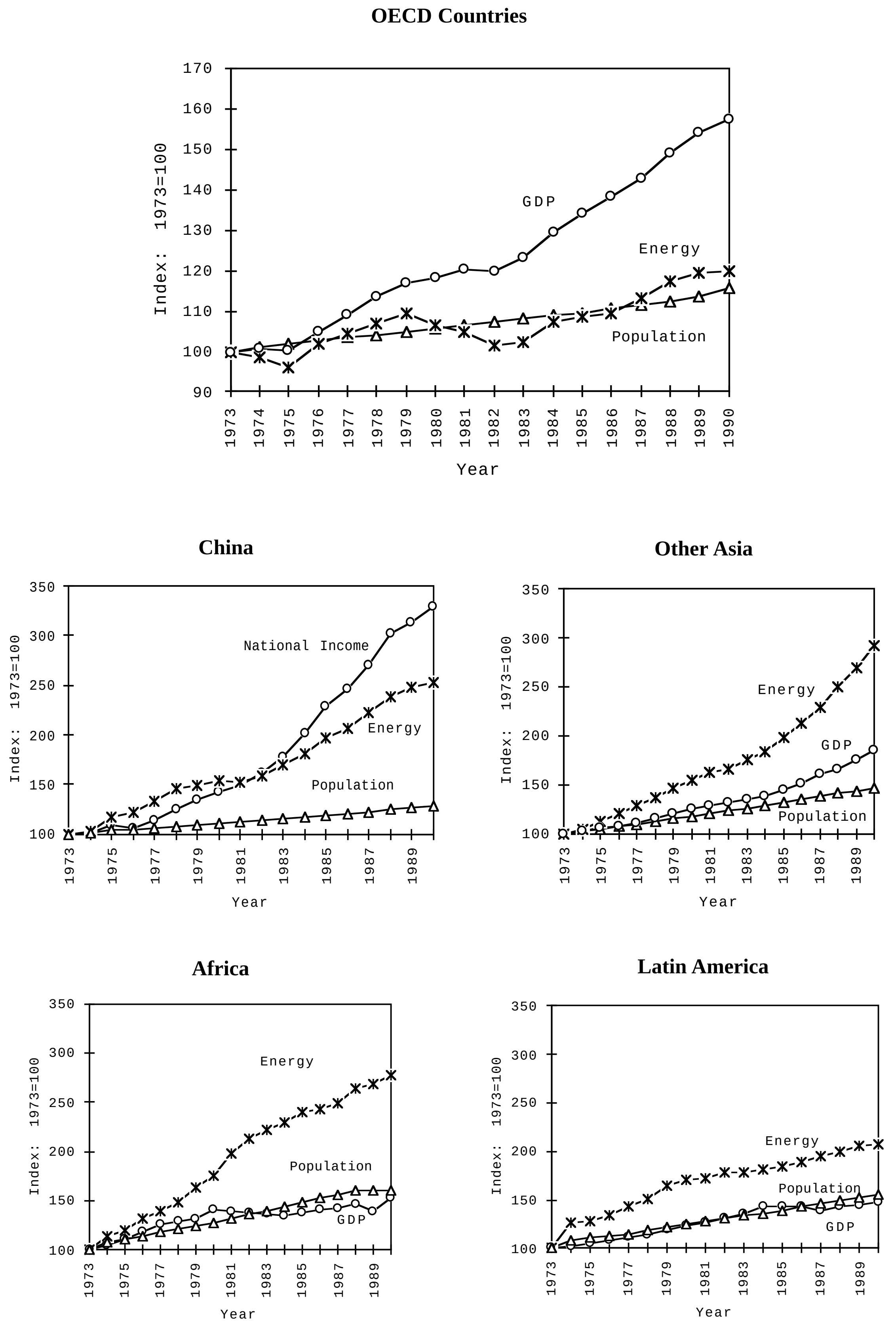
Although energy use and GDP comparisons among regions are useful for setting a context, more detailed information is needed in order to understand the causes of change in energy use and GDP. Closer examination of trends at the subsectoral level provides better insight into the factors driving the changes in energy consumption compared to GDP growth. At this level, both economic energy use indicators (i.e. energy consumed per value-added[3]) and physical energy use indicators (i.e. energy consumed per tonne of product or per unit of service delivered) can be analyzed.

4.0 Industrial Energy Use and Efficiency
4.0 Usage Efficient de l’Energie pour l’Industrie

Industrial production is the backbone for economic output in nearly all countries. In 1992, industry accounted for 43% (3211 Mtoe, 134 EJ) of global energy use and nearly the same proportion of value added for the world economy. The industrial sector is extremely diverse and includes a wide range of activities from the extraction of natural resources, to their conversion into raw material goods, and finally to the manufacture of finished products. Each of these steps requires energy as well as other inputs.

The industrial energy analyses in this paper focus on many of the activities classified under

Figure 3-2 Energy Consumption, GDP, and Population Growth 1973-1990 for Selected Regions of the World.
Sources: GDP data from OECD, 1992; Levine et al., 1991; IMF, 1994. Energy data from IEA, 1994a; British Petroleum, 1994. Data for China from Sinton, 1992.



International Standard Industrial Classification (ISIC) code 03, the manufacturing subsector. This subsector accounts for 60 to 80% of total energy use within the industrial sector, depending on the country. Within manufacturing, a subset of industries exist in which the energy required to produce an additional unit of economic output is three to five times greater than the average energy required for industries overall. This subset of industries can be broadly termed the "raw materials" industries and include iron and steel, chemicals, petroleum refining, pulp and paper, and building materials, as well as others. These industries are generally concerned with the transformation of raw material inputs (e.g., iron ore, crude oil, wood) into usable secondary and tertiary products for an economy.

Because of the great difference in intensity between the energy-intensive industries and all others, changes in the output shares of these industries have a major impact on aggregate manufacturing energy use. The relative share of energy consumption of energy-intensive industries in developing countries has grown from 57% in 1980 to 63% in 1990 (IEA, 1994a) while declining modestly over the same period in OECD countries. This trend partially reflects the migration of energy-intensive industries to developing countries.

4.1 Industrial Energy Intensity Trends in the Energy-Intensive Industries

Table 4-1 shows world primary energy use and physical intensity ranges in 1990 for the raw materials industries highlighted in this paper. Much of the potential for improvement in technical energy efficiencies in industrial processes depends on how closely such processes have reached their thermodynamic limit. For industrial processes that require moderate temperatures and pressures, such as processes in the pulp and paper industry, there exists long-term potential to maintain intensity reduction on the order of 1 to 2% annually. For those processes that require very high temperatures or pressures, such as crude steel formation, the opportunities for continued improvement are more limited using existing processes. However, substitution of materials (e.g. use of plastics for steel), changes in design and manufacture of products resulting in less material use (e.g. composites), greatly increased recycling, and fundamentally new industrial processes can lead to substantial reduction in energy intensity or use.

Technological breakthroughs in the past have included the development of catalytic cracking in petroleum refining and new low-pressure polyethylene production processes. In addition, the amount of raw materials demanded by a society tends to decline as countries reach certain stages of industrial development which also implies a decrease in energy consumption (Ross and Steinmeyer, 1990; Socolow et al., 1994).

4.2 Industrial Energy Intensity Trends by Region

The wide range of subsectors and processes involved in industrial production makes the characterization of energy use patterns for industry, particularly on a global basis, extremely difficult. However, much of the analysis undertaken indicates that a substantial decline in industrial energy intensity has occurred, particularly for industrialized countries, because of efficiency improvements and structural shifts.

Table 4-1 World and Regional Primary Energy Use and Intensities for the Five Most Energy-Intensive Industries, 1990.

Source: IEA, 1994a for primary energy; Levine et al., 1995 for selected energy intensities.

Industry	Primary Energy Use Mtoe	EJ	Energy Intensity (GJ/tonne)
Iron and Steel	443	18.6	20-30
Chemicals	442	18.5	*
Petroleum Refining	286	12.0	3-6**
Pulp and Paper	137	5.7	22-30
Cement	148	6.2	4-6

* Strongly depends on product. For example, ethylene production requires 12-30 GJ/tonne.

** Based on energy use in complex refinery configuration.

OECD Countries

Manufacturing output from OECD countries, estimated at $4114 billion (1985$) in 1994, accounts for about 70% of total manufacturing value added (MVA) produced globally. MVA in OECD countries has grown at an average annual rate of 2% since 1975, similar to overall GDP growth. Between 1980 and 1990, growth in value added occurred in the chemicals and paper and paper products industries, while declines took place in iron and steel and petroleum refining. Total annual manufacturing value added growth rates between 1980 and 1990 in North America and Western Europe of 1.3% and 1.2%, respectively, were below the world average annual growth rate of 2.0%. Japan had a value added growth rate of 3.6% per year during this period (UNIDO, 1993).

Table 4-2 Estimates of Rates of Change in Energy Intensities for Selected Energy-Intensive Products in OECD Countries, 1971-1991 (Growth rates in percent).
Source: Schipper and Meyers, 1992; IEA, 1994a; IISI, 1992.

Sector	Energy/ Value Added (%)	Energy/ Tonne (%)
Chemicals	-3.3	N/A
Building Materials	-1.5	N/A
Petroleum refining	N/A	-0.6
Iron and Steel	-1.8	-1.6*
Pulp and Paper**	-1.6	-0.8

* Values are for 1982-1991.
** Energy per value added values do not include Norway. Physical intensity values are for U.S. only.

Energy consumption grew at an annual rate of 0.8% between 1980 and 1990, indicating a decline in energy intensity of 1.2% per year. A recent analysis of historical manufacturing intensity patterns for ten OECD countries (U.S., Japan, U.K., France, former West Germany, Italy, Sweden, Denmark, Norway, and Finland) shows a significant decline in energy consumed per unit of industrial value added between 1971 and 1991 (Schipper and Meyers, 1992). Table 4-2 shows a more detailed breakdown of trends in energy intensities for OECD countries, presented in terms of energy/value added and in physical units.

One study suggests that nearly three-fourths of the decline in energy intensity as measured in energy per unit of manufacturing value added in the OECD between 1971 and 1991 were the product of improving efficiency in industrial processes (e.g., less energy required to produce a unit of output), with the remaining one-fourth attributable to structural change, or a shift to less energy-intensive industries (Schipper and Meyers, 1992).

Developing Countries

The nature and evolution of the industrial sector has varied considerably among developing countries. Some countries have industries that compete effectively in world markets. Others have industries that have seen relatively little capital investment in the past decade. Many smaller countries have remained primarily agrarian societies with modest manufacturing infrastructure. Also, many of the oil-exporting economies have placed significant capital investment into the petroleum sector, but invested less in other types of manufacturing.

Industrial output and energy use in developing countries is dominated by China, India, and Brazil. China alone accounts for nearly half of total developing country manufacturing energy use and some of the fastest growth in this sector is taking place in China and other countries in Asia.

Manufacturing output for developing countries was $747 billion in 1994 (1985$), about 15% of the world total. Output has doubled since 1975 at an average annual growth rate of 4%, about the same growth rate as experienced in primary energy consumption. The sectors that grew most rapidly included petroleum and coal products, scientific goods, plastic products, and electrical machinery. Food, petroleum refining, electrical machinery, and textiles were the largest in terms of total value added (35%) (UNIDO, 1993).

Value added from energy-intensive industries in Asian countries grew faster than overall manufacturing value added between 1980 and 1990. Latin America experienced a slowdown in growth due to the effects of the debt crisis and regional restructuring during that period; even in this region, energy-intensive industries growth declined less rapidly than overall manufacturing output (UNIDO, 1993).

Table 4-3 Average Annual Growth Rates (%) of Energy Intensity for Selected Energy-Intensive Products in Selected Developing Countries.

	China	India	Korea	Mexico	Brazil	Taiwan
Steel	-1.5	-0.7	-5.1	-2.1	0.6	-2.1
Paper		-0.8		-0.2	-4.1	
Petroleum Ref	-3.0					
Ammonia	-2.5					
Cement	-0.8					

Steel
All values are for the period 1971 to 1991, except for China which is 1982 to 1991. Source: IISI, 1992 and 1993, and IEA, 1994a.
Paper
Growth rates vary by country. Brazil, India, and Taiwan are calculated from 1971. Mexico based on more recent values. Source: IEA, 1994a.
Petroleum Refining
Values are from 1980 to 1992. Source: IEA, 1994a and 1994b.
Ammonia
Value for China is for the period 1981 to 1990. Source: Liu et. al, 1994.
Cement
Value for China is for the period 1985 to 1990. Source: Liu et. al, 1994.

The share of energy-intensive manufactured products such as cement, petroleum products, and iron and steel is expected to continue to increase in the economies of developing countries. More of the demand for energy-intensive products is being supplied intra- and inter-regionally by developing economies, although capital availability (particularly for slower growing regions) may constrain the ability to meet future demand.

Energy intensity trends vary significantly depending on the country and region. In Asian countries, which have accounted for much of the fastest economic growth in developing countries and have had access to current technologies, overall manufacturing intensities as measured in $1980/MJ have consistently declined to around 30 MJ/1980$ between 1970 and 1990 from 50 to 60 MJ/1980$, while the similar figures for Latin American countries indicate a moderate increase over the same period from 25 MJ/1980$ to 30 MJ/1980$ (LBNL, 1993). Physical energy intensity declines are similar to or greater than intensity declines in OECD countries depending on the sector (Table 4-3).

As China, South Korea, and other Asian countries demonstrate, the appropriate policy environment and level of industrial development can cause energy intensities to decline as countries shift toward less energy-intensive production techniques and gain access to more efficient technology. Newer and more innovative approaches will be needed to encourage more rapid reductions in industrial energy consumption in the future in the face of dramatic overall rise in energy consumption.

Given the significant role of developing countries in industrial energy use in the future, it is important to better understand the historical and current trends in manufacturing, particularly for energy-intensive products. This requires detailed analysis of shifts in structure, the impact of new efficient technologies, and the role of energy efficiency policies in reducing industrial energy consumption in order to encourage a more rapid transition to low energy intensities.

Eastern Europe and the Former Soviet Union

In the last five years the economic collapse of EE/FSU can be seen in all industrial output statistics. The EE/FSU has an extremely energy-intensive industrial base, the result of the long-term policy towards materials production that was promoted under the years of central planning. Compared to international standards, the production of energy-intensive goods like steel, cement, ammonia and nitrogenous fertilizers is high, while the output of plastics and paper account for only a small share of industrial activity (Cooper and Schipper, 1991).

Given the difficulties existing in FSU economic statistics, assessing value added of industrial output is by nature imprecise. Two of the most detailed analyses estimated that value added in the industrial sector accounted for 42% to 47% of total national material product in 1988 (Sinyak, 1991; Cooper and Schipper, 1991). Average annual growth rates for manufacturing value added for iron and steel, chemicals, petroleum refining, and paper and paper products for the EE/FSU surpassed world growth in the 1980s, but output dropped significantly after the economic collapse in 1990 (UNIDO, 1993).

Because of limitations in data, comparing industrial energy intensities based on value added or other economic parameters is difficult. Even so, industrial intensity based on value added in the FSU appears to have dropped by more than 2% a year between 1960 and 1985, suggesting a strong decline from a very high base in the energy required for the production of industrial goods (Sinyak, 1991). However, physical intensity data for more recent periods shows little change in intensities for steel, cement, and pulp manufacture (Cooper and Schipper, 1991).

4.3 Industrial Energy Intensity Trends by Subsector

A summary of selected efficient technologies and practices for various energy-intensive industrial subsectors is listed in Table 4-4. The summary is by no means comprehensive, but provides a useful source for identifying the wide range of possibilities that exist within and among industrial sectors for reducing energy demand.

Iron and Steel Industry

Iron and steel production accounts for nearly 10 to 15% of all industrial energy consumption globally (IEA, 1994a). Historical energy consumption for iron and steel production from 1971 to 1991 is shown in Figure 4-1 (energy consumed in the production of coke is not included). Estimated global energy consumption in this subsector was 443 Mtoe (18.6 EJ) in 1990. On average, iron and steel energy consumption in OECD countries declined by about 1% annually with the largest decline in North America. In contrast, energy use in developing countries grew annually by an average of 4%.

Factors Affecting Energy Intensity

Energy intensity in iron and steel production can be affected by several factors, including the mix of products produced, the type and quality of feedstock and fuel input used in the process, and the types of technologies and processes used.

In terms of product mix, the production of higher grade steel products, such as sheet steel, tends to increase energy intensity. Also, production of hot or cold rolled sheets or tubes consumes more energy than the production of ingots or slabs.

The shift to production of more energy-intensive products is partly offset by changes in feedstock, where there has been increased use of scrap in primary and secondary steelmaking, which significantly reduces energy requirements. In the U.S., scrap accounts for nearly 60% of raw materials used in steel production. The availability of scrap for future production will be determined by the scrap recovery rate, the availability and cost of scrap and scrap substitutes, and the ease of transport and trade of scrap (Fruehan et al., 1994).

The switch from open hearth furnace (OHF) technology to basic oxygen furnace (BOF) results in an intensity drop of about 1 to 3 GJ/tonne, although the potential reduction is highly dependent on the molten iron/scrap ratio (Ross and Liu, 1991; Steiner, 1995). However, the most significant reductions

Table 4-4 Energy-Efficient Technologies and Practices for Selected Industries.
Source: Levine et al., 1995.

Iron and Steel

- Heat recovery for steam generation, pre-heating combustion air, high efficiency burners, and partial replacement by pelletization for sinter plants
- Adjustable speed drives, coke oven gas compressors, heat recovery coke oven gases, and dry coke quenching
- Efficient hot blast stove operation, waste heat recovery for hot blast stove, top gas power recovery turbines, direct coal injection
- Recovery BOF-gas, heat recovery of sensible heat BOF-gas, closed BOF-gas-system, optimized oxygen production, increase scrap use, efficient tundish preheating
- UHP-process, Oxy-fuel injection for EAF plants
- Efficient ladle preheating, new furnace types for DC-arc furnaces
- Heat recovery (steam generation), recovery of inert gases (Ar, etc.), efficient ladle preheating
- Use of continuous casting
- 'Hot connection' or direct rolling, recuperative burners in reheating furnace
- Heat recovery, efficient burners annealing and pickling line, continuous annealing operation

Petrochemicals

- Process management and thermal integration (e.g. optimization of steam networks, heat cascading, low and high temperature heat recovery, heat transformers)
- Mechanical vapor recompression and new compressor types
- New catalysts
- Adjustable speed drives
- Selective steam cracking membranes
- High temperature cogeneration and heat pumps
- Autothermal reforming

Petroleum Refining

- Reflux overhead vapor recompression, staged crude pre-heat, mechanical vacuum pumps, intermediate reboilers and condensers
- Fluid coking to gasification, turbine power recovery train at the FCC, hydraulic turbine power recovery, membrane hydrogen purification, unit to hydrocracker recycle loop
- Improved catalysts (reforming), and hydraulic turbine power recovery

Pulp and Paper

- Continuous digester, displacement heating/batch digesters, indirect heating/batch digesters, anthraquinone pulping, chemimechanical pulping
- Oxygen predelignification, oxygen bleaching, displacement bleaching
- Tampella recovery system, falling film black liquid evaporation, lime kiln modifications, turbumix system
- Improved boiler design/operation (Cogeneration), and distributed control systems

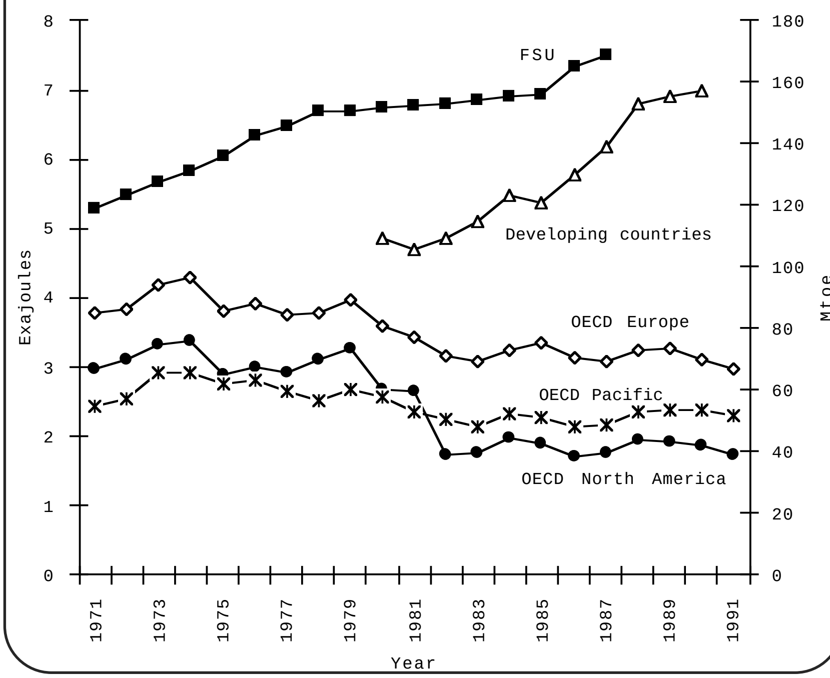
Cement

- Improved grinding media and linings, roller mills, high-efficiency classifiers in closed-circuit grinding plants, waste heat drying using preheater exit gases, wet process slurry dewatering with filter presses and slurry thinners
- Low pressure-drop cyclones for suspension reheaters, material recirculation in flash precalciners, kiln combustion system improvements, enhancement of internal heat transfer in kiln, kiln shell loss reduction, optimize heat transfer in clinker cooler, use of waste fuels, dry-suspension preheater kilns, dry -precalciner kilns, blended cements, cogeneration, high-temperature ceramic filters for exhaust
- Modified ball mill configuration, particle size distribution control, improved grinding media and linings, high-pressure roller press for clinker pre-grinding, high-efficiency classifiers in closed circuit plants, roller mills

in intensity result from the use of electric arc furnace (EAF) technology which consumes about half as much energy because it does not require the production of pig-iron in the highly energy-intensive blast furnace. The use of EAF has increased to nearly one-third of overall production globally between 1982 and 1993.

Switching from ingot casting to continuous casting results in significant increases in product yield, thereby reducing energy consumption per unit. The desire to reduce manufacturing cost through increased yields has been the main driving force in the world shift to continuous casting technology (Obenchain, 1995; Steiner, 1995).

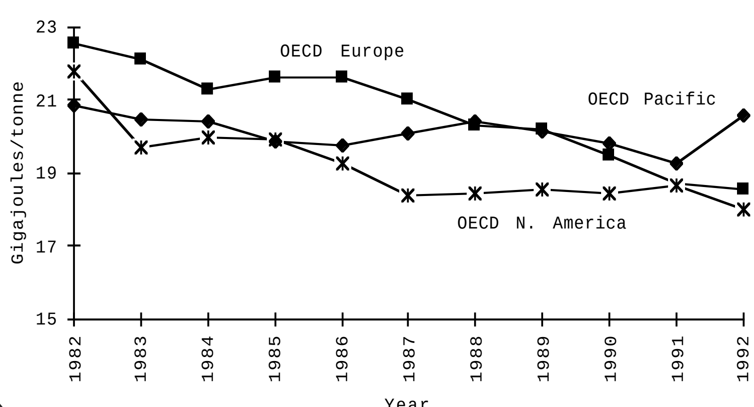
Figure 4-1 Energy Consumption in the Iron and Steel Industry by Region, 1971-1991.
Source: IEA, 1994a; Cooper and Schipper, 1991.



Energy Intensity Trends

Physical energy intensities for steel production in OECD countries are shown in Figure 4-2. Aggregate intensities dropped by an average of about 1.6% annually with the largest declines in Europe and North America. Energy per unit of manufacturing value added in the iron and steel sector for ten OECD economies declined by 1.9% annually between 1971 and 1991, with the steepest declines in the Scandinavian countries (Schipper and Meyers, 1992). The decline in intensity in OECD countries is partly a result of process shifts toward EAF technology as well as process improvements such as continuous casting.

Figure 4-2 Historical Physical Energy Intensities for Crude Steel Production for OECD Countries, 1982-1992.
Source: IEA, 1994b; IISI, 1992.



For the EE/FSU, intensities range between 20 and 45 GJ/tonne within the region and have declined very little during the time period. Intensities in developing countries can also vary significantly. Modern facilities in Asia show energy efficiencies similar to OECD countries, while other developing countries often have much higher intensities. In the 1970s and 1980s, intensities declined the most in Asian countries; other regions show much flatter changes. Intensities for China are higher, partly because they include energy provided to employees for living. When adjusted for these and other category uses, intensities were about 20% higher than average U.S. intensities (Ross and Liu, 1991).

Estimates of Overall Energy Savings

A recent study estimated that primary energy use in the iron and steel industry in the United States will remain at about the same level of approximately 48 Mtoe (2 EJ) per year in 2010, assuming use of current practices and production of 84 Mt of raw steel compared with 98 Mt in 1989. By implementing state-of-the-art technologies, energy use could fall 22%, to 37 Mtoe (1.56 EJ). Implementation of advanced technologies could further reduce energy consumption by another 10%, to 33 Mtoe (1.4 EJ). This is a savings of about 30% over the base case (U.S. Dept. of Energy, OIT, 1990).

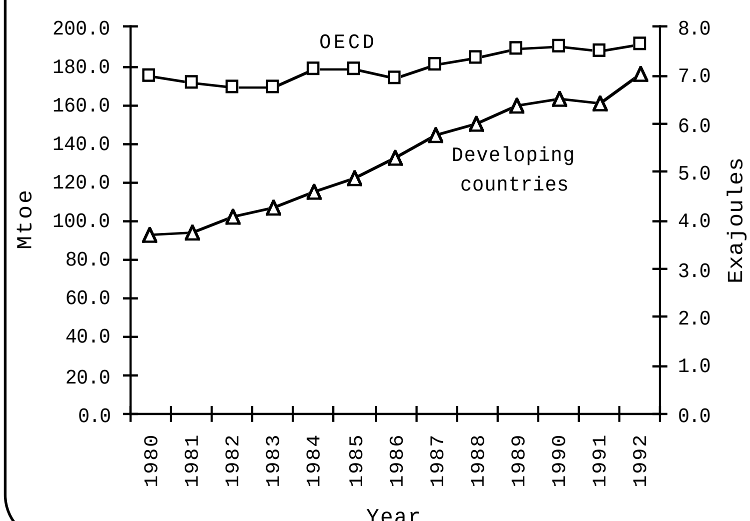
Estimates of the potential energy efficiency of current steel production for some countries and regions by the year 2000 range from about 15 to 60%, with some of the largest savings possible in the formerly planned economies of eastern Europe and China as well as Spain and the United States (Worrell, 1994).

Our analysis found that global primary energy use for iron and steel production is expected to grow from 443 Mtoe (18.6 EJ) in 1990 to 606 Mtoe (25.4 EJ) in 2020 under a business-as-usual scenario. Adoption of state-of-the-art technologies in two-thirds of the global capacity will lead to growth in energy consumption of 17% to 535 Mtoe (22.4 EJ) in 2020. Under an ecologically-driven/advanced technologies scenario, primary energy consumption will remain at about 1990 levels, reaching only 466 Mtoe (19.5 EJ) in 2020 (Levine et al., 1995).

Chemicals Industry

Figure 4-3 depicts chemicals energy consumption for OECD and developing countries from 1980 to 1992 (IEA, 1994a). Estimates for consumption in the EE/FSU are not shown because of lack of aggregated reporting although other sources suggest that the EE/FSU consumed between 95 and 170 Mtoe (4 and 7 EJ) annually, levels similar to those in developing countries during the period (Cooper and Schipper, 1991). Depending on the country, feedstocks can account for between 10% and 40% of total chemicals energy consumption. The production of bulk chemicals consumes the largest amount of energy in the chemicals sector, accounting for nearly 25% of total energy consumption. This discussion focuses on four bulk inorganic and organic chemicals: ethylene, ammonia, methanol, and chlorine.

Figure 4-3 **Chemicals Energy Consumption by Region.**
Source: IEA, 1994a.



Ethylene

The production of petrochemicals such as ethylene, propylene, and butadiene by steam cracking of hydrocarbon feedstocks is the single most energy-consuming process in the petrochemicals sector. For modern steam crackers the specific energy use per tonne of ethylene (excluding feedstock energy) varies between 13 GJ/tonne for ethane feedstock and 25 GJ/tonne for gas oil feedstock (Hydrocarbon Processing, 1995). Including feedstock use, steam cracking plants in the U.S. consume about 68 GJ/tonne, of which a large part is feedstock (U.S. Congress, OTA, 1993). In the Netherlands, the specific energy consumption for steam cracking of naphtha was estimated at 58 GJ/tonne primary energy including feedstocks (Worrell et al., 1994b). Estimates for average intensities in China range from 73 to 90 GJ/tonne using a relatively heavy feedstock mix (China Energy Research Society, 1993; Yang and Zeng, 1994). Significant technology improvements in the production of ethylene have mainly included process integration, energy recovery, and improved process control.

Ammonia and Methanol

For ammonia, two of the main production processes for the manufacture of hydrogen as a reactant gas for synthesis gas are the partial oxidation of hydrocarbons and steam reforming. The theoretical minimum energy requirement to produce ammonia in the steam reforming of natural gas amounts to 19.1 GJ/tonne (Lower Heating Value (LHV)), including feedstocks.[4] Modern steam reforming plants consume 30 to 31 GJ/tonne, and recent estimates for energy use for ammonia production in Europe ranged from 33 to 44 GJ/tonne, depending on the country (Worrell et al., 1994a). For developing countries ,ammonia energy consumption and intensity can vary dramatically depending on the type of technology installed. In China, for example, where ammonia production is still dominated by small and medium-size plants, unit energy consumption can run 20 to 25% higher than plants of recent design.

Energy consumption for methanol production using today's newest technology is 28 to 33 GJ/tonne (Hydrocarbon Processing, 1995). Consumption can vary depending both on feedstock and technology used for production. For new units under construction, unit energy consumption for bulk chemical processes within plant boundary limits exhibit much less variation than in the past where plants are designed and constructed by large engineering firms with worldwide operations (Silva, 1995).

Chlorine

Chlorine is produced through the electrolysis of sodium chloride which requires significant amounts of electrical energy. Typically, electricity requirements for chlorine vary between 2850 and 3500 kWh/tonne (35 to 41 GJ/tonne) depending on the cell type used. The secondary evaporation step can also require a significant amount of energy, especially for the diaphragm cell process. The membrane cell technology, which is the most promising, requires less energy than the diaphragm cell and a smaller amount of energy is required for evaporation. The theoretical minimum for the production of one tonne of chlorine in electrolysis is 18 GJ/tonne of primary energy assuming an electricity conversion ratio of 3.1 (Smit et al., 1994).

Estimates of Overall Energy Savings

Among major energy-intensive hardware components, improvements have recently been made in distillation and in gas turbines. Improved catalysts are continuing to be developed which enable increased yields and decreased unwanted by-products and/or decreased temperatures and pressures. A related area of major on-going improvement is in control systems. With increasing computational capability, new sensors are being developed and on-line controls implemented. Improved process integration and optimization, particularly of heat gains and losses, holds out a potential for energy savings. Also, biotechnology, including bio-processing of petroleum feedstocks, bio-processing of ordinary biological feedstocks, and growing new kinds of plants which have high yields of downstream products, has longer-term potential for energy savings.

The technical potential for savings compared with best practice in Europe is estimated at 12% for ethylene (Worrell et al., 1994b). Studies of the U.S. ethylene industry suggest a potential 6% reduction in energy consumption from baseline levels using state-of-the-art technologies, and a reduction of 11% from baseline levels using more advanced technologies (U.S. Dept. of Energy, OIT, 1990). State-of-the-art specific energy consumption for making ammonia by reforming natural gas is 28 GJ/tonne and for partial oxidation of oil residues is 30 GJ/tonne. In the chlor-alkali industries, the use of membrane cells can result in significant reductions in energy consumption. One study estimated that potential advanced technology membrane cells can reach levels of energy consumption of 24 GJ/tonne by 2015, or an average reduction in intensity of 1.9% per year from current levels (Smit et al., 1994).

Our study found that energy use for worldwide chemical production will increase from 442 Mtoe (18.5 EJ) in 1990 to 640 Mtoe (26.8 EJ) in 2020 with business-as-usual production. Adoption of state-of-the-art technologies will result in a decline in consumption to 520 Mtoe (21.8 EJ) in 2020, 20% below the business-as-usual baseline. Energy consumption slightly lower than 1990 levels is seen in the ecologically-driven/advanced technologies scenario (Levine et al., 1995).

Petroleum Refining Industry

Along with chemicals and primary metals production, petroleum refining is one of the three largest energy-consuming industries in the United States and the third largest in the European Union (Worrell, 1994). Figure 4-4 shows total primary energy consumed for petroleum refining in OECD countries. Between 1978 and 1992, refining energy consumption declined about 1% a year. North America still accounts for about half the total refining energy use in OECD countries as well as about half the output.

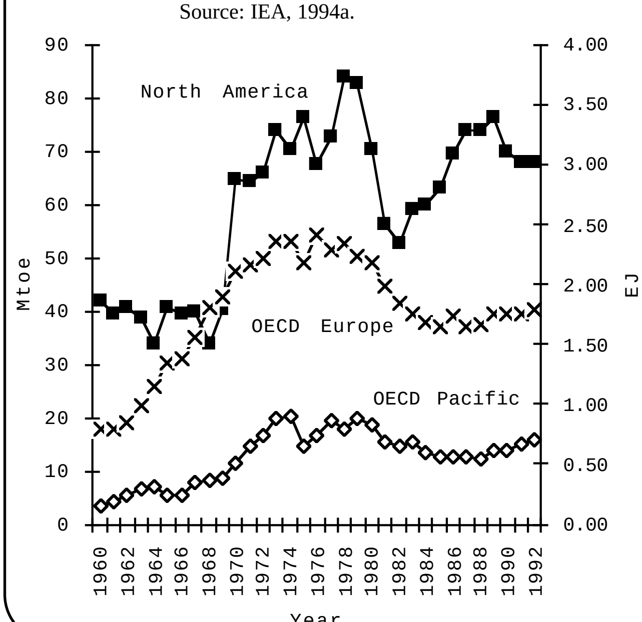
Developing countries and the EE/FSU account for about 25% and 30% of world refining energy consumption, respectively. Growth in consumption for both regions has been rapid (about 3 to 5% annually), although consumption in EE/FSU countries has declined recently due in part to the economic downturn. In developing countries, most of the growth has occurred in Asia (6% annual growth) and the Middle East (3% annual growth), with flatter growth in Africa and Latin America.

Factors Affecting Energy Intensity in Refining

Aggregate energy intensity in petroleum refining is affected by refinery complexity, product mix, type of technology and process used, and the type of feedstock being processed. Complex, modern refinery systems tend to have much higher intensities than more simple distillation units, mainly due to additional energy requirements associated with conversion and finishing processes. Some of the more intensive processes associated with complex refineries include hydrogen manufacture, recovery of sulfur, and hydrotreating.

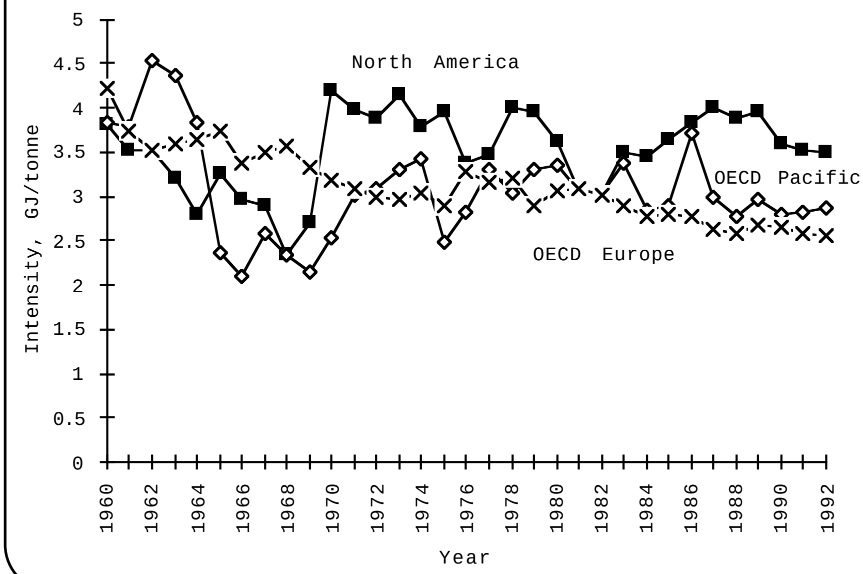
The production of high-octane reformulated gasoline is a much more energy-intensive process than the production of fuel oil. The high demand for clean, light distillate products, particularly in OECD countries, increases energy intensities in modern

Figure 4-4 Petroleum Refining Energy Use in OECD Countries 1960-1992.
Source: IEA, 1994a.



refineries. Processes improvements center around reduction in the input energy requirements for particular processes, capture and use of waste heat, and the development of new process technologies that require less energy.

Figure 4-5 Aggregate Physical Energy Intensities for Oil Refining in OECD Countries, 1960-1992.
Source: IEA, 1994a.



A large number of refineries in developing countries were built before the oil price shocks of the 1970s, and were designed to optimize only capital costs rather than total refinery costs. For refineries in developing countries of comparable complexity to efficient OECD refineries, fuel use to process the crude can run up to 15 to 20% of the intake fuel, almost double that of modern refinery systems (Ghamarian, 1995). The incorporation of heat integration retrofits can significantly reduce unit energy consumption in these refineries.

Energy Intensity Trends

Figure 4-5 identifies historical physical intensities of refinery processing in OECD countries as measured in primary energy per tonne of product produced. For the period shown, intensities declined by about 1% per year, although more rapid declines were seen in OECD Europe. In 1992, the average intensity for all three regions was about 3.1 GJ/tonne. The higher intensities in North America are partly due to the higher proportion of gasoline (and other high-end distillates) in the production mix.

Aggregate intensities for refining energy use for developing countries and the EE/FSU in the early 1990s averaged 3.6 GJ/tonne and 6.0 GJ/tonne, respectively. Aggregate refining intensity for developing countries declined by about 1.5% per year between 1971 and 1992. One of the main causes for the relatively low intensity in developing countries is the much less complex refinery structure and the production of a much higher proportion of heavier products (fuel oil). In addition, the rapid dissemination of modern refinery technology, particularly in boom areas such as southeast Asia, contributes to lower intensities. Refining intensities in China have declined from 3.8 GJ/ton in 1980 to around 3.0 GJ/ton in 1990 (People’s Republic of China, State Planning Commission, 1993).

Intensities in the EE/FSU region have increased between 1971 and 1990. The existing data suggest 5 to 6% annual growth in aggregate intensities. Antiquated technologies and processes in many former Soviet refineries are responsible for the high levels of energy consumption.

Estimates of Energy Savings

One study estimated that energy intensity for the production of refinery products in state-of-the-art European refineries were on the order of 15% lower than average (Worrell, 1994). Another study estimated that energy consumption in the United States for petroleum refining would be just over 70 Mtoe (3 EJ) in the year 2010 assuming no technological advances. By implementing state-of-the-art technologies, energy use in 2010 is estimated to be reduced by about 20% to 60 Mtoe (2.5 EJ). Implementation of advanced technologies, defined as technologies in the conceptual stage or under development, is expected to further reduce energy consumption in the year 2010 by 10% to about 54 Mtoe (2.25 EJ). This is a savings of 28% over the base case (U.S. Department of Energy, OIT, 1990).

Our analysis found that world primary energy use for petroleum refining will grow 29% from 286 Mtoe (12 EJ) in 1990 to 402 Mtoe (16.8 EJ) in 2020 under a business-as-usual scenario. Energy consumption grows by 17%, to 346 Mtoe (14.5 EJ) by 2020 with the implementation of state-of-the-art technologies. Under an ecologically-driven/advanced technology scenario, global primary energy use for petroleum refining declines slightly compared to 1990 levels (Levine et al., 1995).

Pulp and Paper Industry

The pulp and paper industry consumed an estimated 136 Mtoe (5.7 EJ) of purchased (or commercial) energy in 1990. It is the fourth largest energy-consuming industry in the United States and the European Union, accounting for 10% of U.S. industrial energy consumption in 1988 (U.S. Congress, OTA, 1993; Worrell et al., 1995b). It is also fourth in China, Indonesia, Korea, and Thailand, behind iron and steel, non-metallic minerals, and chemicals (Ishiguro and Akiyama, 1994).

Factors Affecting Energy Intensity

The most important factors affecting the amount of purchased energy consumed in the paper industry worldwide are the amount of self-generated fuels used, the share of waste paper, the pulping process, and mill size. The ratio of pulp to paper produced is an important factor to explain differences between countries or regions.

More than 56% of the U.S. industry's total energy consumption in 1992 was provided through self-generated and residue fuels (hogged fuel, bark, and spent liquor) (Pulp & Paper International, 1995). In the Canadian pulp and paper industry, 52% of the energy consumed in 1990 was self-generated (Clayton, 1995).

The share of waste paper as a raw material input influences the amount of energy consumed at a mill (de Beer et al., 1994). Only 10 to 30% of the energy required to make chemical pulp from wood is needed to produce pulp from waste paper (Ishiguro and Akiyama, 1994). The production of primary newsprint from mechanical pulp in the United States requires about 25 GJ/tonne, while the production of secondary newsprint from waste paper requires about 15 GJ/tonne, saving about 10 GJ/tonne of mostly electric energy (Elaahi and Lowitt, 1988).

Worldwide, recycling has grown from recovery of 30% of paper and paperboard in the early 1980s to 35% in 1989. The United States paper industry consumed 26.5 Mt of recovered paper in 1994, 31.5% of the industry's papermaking fiber share. In 1990, 52% of the paper and paperboard consumed in Japan was recycled for making paper products (Ishiguro and Akiyama, 1994). Use of waste paper in the European Union is about 50%, and ranges from 27% in Belgium to 69% in the Netherlands (VNP Jaaroverzicht, 1990).

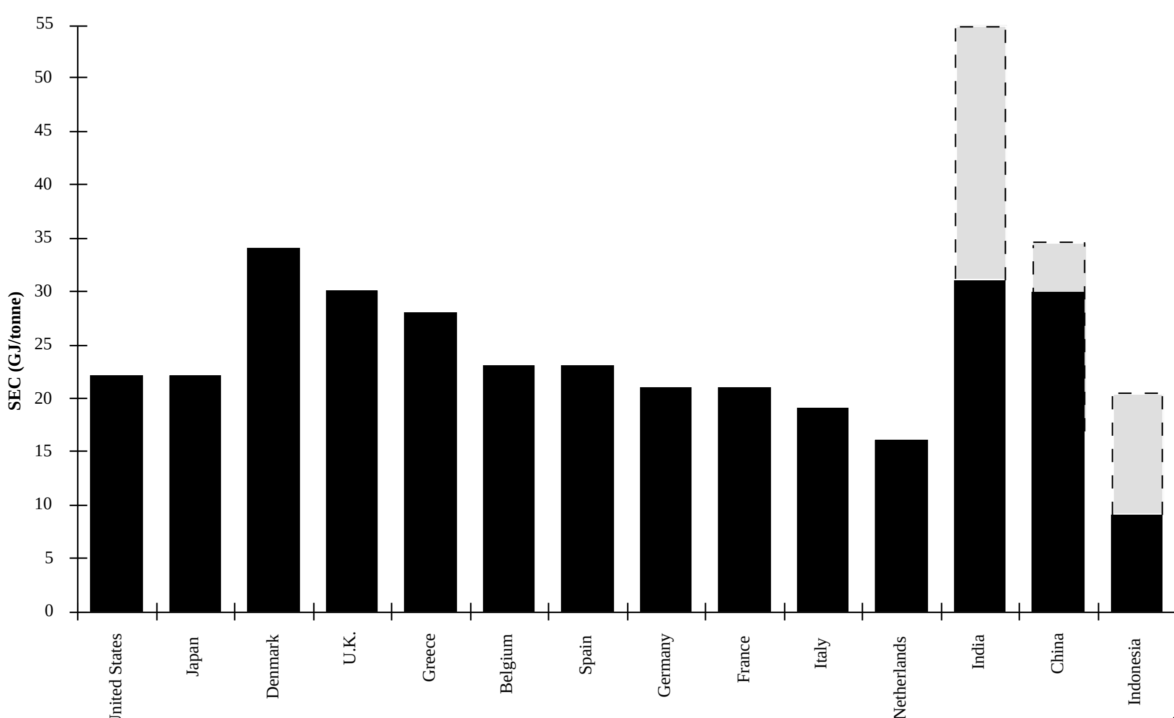
In Japan, France, and the United States there has been a shift from the electric-intensive mechanical and semi-chemical pulping processes to less electric-intensive chemical pulping. In contrast, due to the growth of mechanically produced exported newsprint, Sweden has moved toward the more electric-intensive mechanical pulping process (Kahane, 1989).

Figure 4-6 shows primary specific energy consumption for the pulp and paper industry for selected countries. The U.S. pulp and paper industry's specific energy consumption (SEC) decreased from 26 GJ/tonne in 1972 to 22 GJ/tonne in 1992, a reduction of about 0.8% per year (Pulp & Paper International, 1995; U.N. FAO, 1983; 1986; 1992). The efficiency gains during this period are a result of increased cogeneration, improved waste heat recovery, increased chemical and wood residue recovery, application of improved process control technologies, and closing of older, less-efficient mills (Elaahi and Lowitt, 1988).

An analysis of primary SEC for the European Union found that energy use ranged from about 16 GJ/tonne in the Netherlands to about 30 GJ/tonne in the U.K. in 1988 (Worrell et al., 1995b). The SEC for the Japanese paper industry in 1992 is estimated to be about 22 GJ/tonne (Nagata, 1995). One estimate found overall SEC in the Indian pulp and paper industry to range from 30.6 to 55.3 GJ/tonne. The large variation is explained by the fact that only about 10% of the country's capacity are large, integrated mills, 10% are medium-size, and the remaining 80% are small mills (Tata Energy Research Institute, 1994). The high SEC is mainly due to small mill size, use of old technology, lack of energy-efficient devices, and lack of cogeneration. However, the largest Indian paper mill is reported to use 42 GJ/tonne (Ishiguro and Akiyama, 1994).

The paper industry in China, the fourth largest producer of paper and paperboard worldwide, relies mostly upon antiquated technology used in small-scale production facilities. China also has inferior quality raw materials and does not adequately recover energy at the mills. Official reporting on energy use covers only the large-scale, more efficient plants. One Chinese government estimate of the primary energy SEC was 30 GJ/tonne in 1985 (Ishiguro and Akiyama, 1994). Another estimate suggests energy consumption of 32.5 GJ/tonne in 1992, and 34 GJ/tonne in 1993 (Sinton, 1995).

Figure 4-6 Primary SECs for Pulp and Paper Industry in Selected Countries.
Sources: Pulp and Paper International, 1995; U.N. FAO, 1983, 1986, 1992; Worrell, 1994; Nagata, 1995; Tata Energy Research Institute, 1994; Ishiguro and Akiyama, 1994. Note: SECs are based on data for the following years: U.S., Japan, and China - 1992, European countries - 1988, Indonesia - 1989, India - 1984. Shaded areas represent ranges in estimated SECs.



Estimates of Overall Energy Savings

A recent study estimated that pulp and paper industry primary energy use (including self-generated fuels) in the United States would grow from 67 Mtoe (2.8 EJ) in 1990 to 110 Mtoe (4.6 EJ) in 2010 assuming current practices and an annual 2.5% growth in production from 1990 levels to of 125 Mt in 2020. By implementing state-of-the-art technologies energy use could fall 30% to 76 Mtoe (3.2 EJ) in 2010. Implementation of advanced technologies could further reduce energy consumption by another 25% to 57 Mtoe (2.4 EJ). This is a savings of about 50% from that of the base case (U.S. Department of Energy, OIT, 1990).

An analysis of the energy savings potential in the European Community using available energy technologies estimated savings of between 20 and 30% (Bateman, 1992). Another study estimated savings of 33% by the year 2000 in the pulp and paper industry in the Netherlands through implementation of 21 state-of-the-art measures, including optimization of process control, waste heat recovery, and installation of the long nip (extended nip) press (de Beer et al., 1993).

Near-term savings of 20 to 25% are estimated for the Indian pulp and paper industry through measures such as increased chemical recovery and cogeneration (Tata Energy Research Institute, 1994). Near-term potential efficiency improvements in Indonesia, Korea, and Thailand are estimated to be 30%, 15%, and 17%, respectively (Ishiguro and Akiyama, 1994).

We estimate that pulp and paper industry primary energy consumption will increase 48%, from 137 Mtoe (5.7 EJ) in 1990 to 265 Mtoe (11.1 EJ) in 2020 under a business-as-usual scenario. Adoption of state-of-the-art technologies will lead to consumption of 221 Mtoe (9.2 EJ) in 2020. Under an ecologically-driven/advanced technology scenario, energy consumption increases to 184 Mtoe (7.7 EJ) in 2020 (Levine et al., 1995).

Building Materials Industry

Figure 4-7 shows energy consumption for building materials worldwide (IEA, 1994a). Developing countries now consume more energy for building materials than the OECD countries or the FSU. This discussion focuses on production of cement, by far the largest energy-consuming commodity in the subsector.

The cement subsector accounts for an estimated 2% of world primary energy demand annually (Worrell et al., 1995a). Primary energy consumption for cement manufacturing in 1988 was dominated by China and the FSU which used 29 Mtoe (1.2 EJ) and 25 Mtoe (1.0 EJ),

Figure 4-7 Energy Consumption for Building Materials by Region, 1980-1990.
Source: IEA, 1994a.

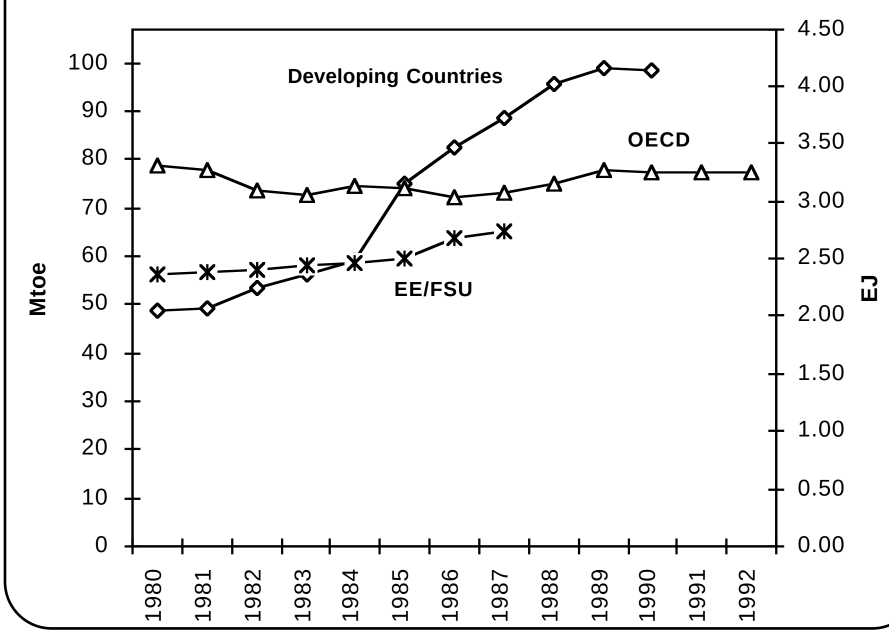
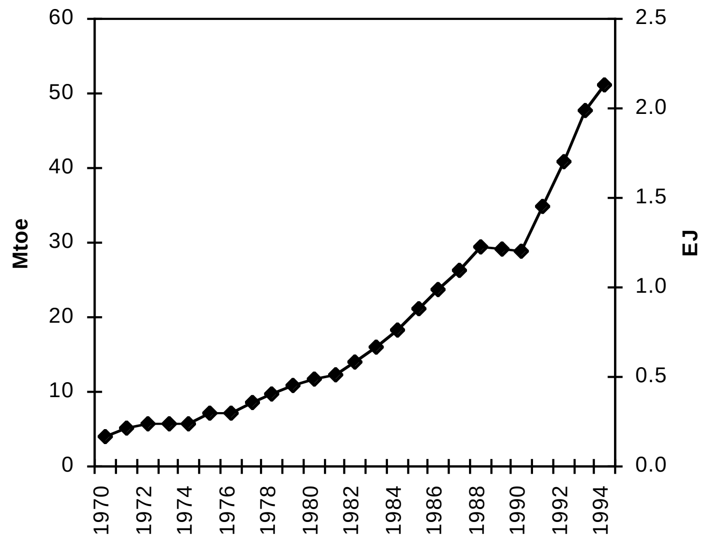


Figure 4-8 Primary Energy Use for Cement Production in China, 1970-1994.
Source: U.N., 1983, 1993; People's Republic of China, State Statistical Bureau, 1994; Sinton, 1995.



respectively. China's energy use has almost doubled since 1988, reaching 51 Mtoe (2.1 EJ) in 1994 (Figure 4-8) (Sinton, 1995). The largest European primary energy consumers are Italy, France, and Germany, each of which consumed over 2 Mtoe/year (0.1 EJ) for cement production (Worrell, et al., 1995a; 1995b).

In the U.S., primary energy consumption for the cement industry was 9 Mtoe (0.4 EJ) in 1988. Between 1975 and 1988, energy consumption in this sector dropped by about 25%. However, electricity consumption stayed relatively flat for the period, despite the overall reduction in energy use, indicating an increasingly electricity-intensive industry, especially since production of cement increased during the same period (U.S. Dept. of Energy, OIT, 1990). This is explained by the increasing share of electricity-intensive dry kilns in the U.S.

Factors Affecting Energy Intensity

Average specific energy consumption (SEC) levels for cement production range from about 2 to 7 GJ/tonne, depending on the country and process used (Worrell, et al., 1995a). The intensity of cement production is influenced by the share of dry vs. wet process used in production, the clinker-to-cement ratio, and the type of kiln (rotary vs. vertical).

In the United States, the dry process typically uses between 3.5 to 4.5 GJ/tonne of cement, while the average wet process uses over 5.2 GJ/tonne (U.S. Dept. of Energy, OIT, 1990). Estimates vary, but a full conversion from a long-wet kiln to a preheater/precalciner kiln yields fuel savings of 45% or more (Fog and Nadkarni, 1983). Theoretically, SECs of 3.0 GJ/tonne for the wet process and 1.5 GJ/tonne for the dry process are possible (Lazarus, 1993). In 1980, only about 35% of world cement was still produced by the wet process. While Germany and France use only 3% and 10% wet process, respectively, use hovers around 50% in developing countries and is as high as 85% of production in the FSU (Lazarus, 1993). In the United States, the wet process was used for 35% of production in 1990 (van der Vleuten, 1994).

The energy intensity of cement production is directly proportional to the amount of additives used relative to clinker (van der Vleuten, 1994). Some of the additives that can be blended with clinker to reduce the energy intensity of cement production include blast furnace slags, fly-ash, and natural pozzolanes (volcanic material). Blast furnace slags are produced in the production of pig-iron, while fly ash is produced during the combustion of coal for electric power generation. Clinker to cement ratios are typically between 70 and 90% in Eastern Europe and between 80 and 90% in Latin America. The U.K., United States, Denmark, Ireland, and Portugal all have ratios above 90%, while the Netherlands has a remarkably low ratio of 27%, partially due to the high cost of imported clinker but also due to the high share of blast furnace cement (Worrell et al., 1995a).

Rotary kilns (which typically operate at 1500-1600°C) are more efficient than small-scale vertical kilns. About 70% of worldwide capacity is rotary kilns (with or without preheater or precalciner systems). Vertical kilns, which are usually used in more remote areas where large scale plants are not economically viable, can be found in Yugoslavia, Kenya, India, and China.

Physical Energy Intensity Trends

Primary SECs in the OECD range from a low of 2.1 GJ/tonne in the Netherlands to a high of 5.9 GJ/tonne in Denmark. The variations are largely explained by differences in clinker-to-cement ratios, but are also caused by variations in technology.

SECs in the EE/FSU range between 4.7 GJ/tonne and 7.3 GJ/tonne, because there are many facilities that use wet process kilns, equipment efficiency is low, and the clinker-to-cement ratios are high (Worrell, et al., 1995a). Both Russia and Ukraine have raw materials with high moisture content and have had difficulties adopting the dry process. The cement industry in Hungary, former Yugoslavia and the Czech Republic is relatively modern. Hungary, Poland, FSU, and the Czech Republic produce large amounts of blended cements, including blast furnace slag cement and Portland fly ash cement (van der Vleuten, 1994). The Latin American cement industry grew significantly during the 1960s and 1970s and a number of production facilities now use the dry process. SECs in Latin America range from a low of 4.3 GJ/tonne in Guatemala to a high of 6.2 GJ/tonne in Uruguay (Worrell, et al., 1995a).

In China, 70% of production is based on small, vertical kiln equipped plants and only 5% is produced in modern precalciner kilns (Liu, et al., 1995). The SEC for production of cement in large and medium plants was 6.5 in 1992, down from 7.6 in 1970 (Sinton, 1995). In many Asian countries, the wet process still accounts for the majority of total production; however, the more efficient dry process is rapidly being installed in the faster growing industries of East Asia (van der Vleuten, 1994). Blended cements are used in some Asian countries, including India and China.

Estimates of Overall Energy Savings

A study of potential energy savings in the U.S. cement industry estimated that primary energy use would be 11.23 Mtoe (0.47 EJ) in 2010 using current practices, up from 9.8 Mtoe (0.38 EJ) in 1988. Implementation of state-of-the-art technologies is estimated to decrease energy use to 8.4 Mtoe (0.35 EJ), a savings of 26%. Advanced technologies could further reduce energy consumption by another 34% to 5.0 Mtoe (0.23 EJ) by 2010. This is a savings of 50% over the current practices (U.S. Dept. of Energy, OIT, 1990).

A study of potential energy savings in the cement industry in selected OECD, EE/FSU, and Latin American countries found potential savings up to 57% based on use of the best available technology in 1990. The larger savings identified are for those countries that have a high percentage of production using the wet process. Further reductions of up to 25% were estimated through replacing clinker and using blended cements. Potential SECs based on these savings ranged from 1.8 GJ/tonne in the Netherlands to 3.8 GJ/tonne in Costa Rica and El Salvador (Worrell, et al., 1995a).

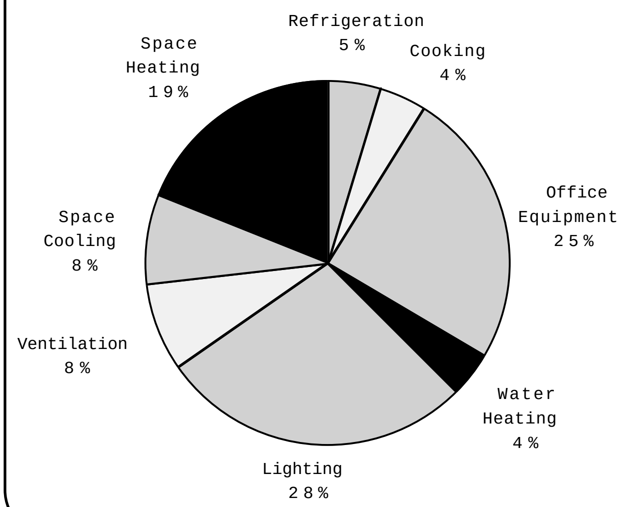
A study of energy use in the cement industry in China found the SEC for clinker production could be reduced by about 30% (to approximately 3.6 GJ/tonne) by the year 2000 through the adoption of advanced mechanized vertical kilns and additional precalciner kilns (Liu et al., 1994).

Our analysis found that global primary energy use for cement production will grow 46%, from 148 Mtoe (6.2 EJ) in 1990 to 274 Mtoe (11.5 EJ) in 2020 under a business-as-usual scenario. Adoption of state-of-the-art technologies will lead to consumption of 219 Mtoe (9.2 EJ) in 2020. Under an ecologically-driven/advanced technology scenario, primary energy use will remain at about 1990 levels, reaching 157 Mtoe (6.6 EJ) in 2020 (Levine et al., 1995).

5.0 Buildings Energy Use and Efficiency
5.0 Usage Efficient de l'Energie pour Edifices

Like the industrial sector, the buildings sector is both complex and varied. The sector is typically divided into residential and commercial subsectors. Each subsector includes a wide variety of specific energy applications including cooking, space heating and cooling, lighting, food refrigeration and freezing, office equipment, and water heating. These applications are often known as end-use services, emphasizing the concept that what is important is not the energy consumed but the service delivered—cooked food, a warm space, or a lit office. Figure 5-1 shows energy demand by end-use for the commercial sector in the U.S.

Figure 5-1 Buildings Energy End-Uses for Commercial Buildings in the U.S.
Source: US Congress, OTA, 1992b.



Global primary energy consumption in the buildings sector has grown 2.7% annually from 1971 to 1992, with growth more than twice as rapid in developing countries (Table 5-1). Buildings consumption in 1992 was 2490 Mtoe (104 EJ), with OECD countries accounting for a 60% share and the remaining share of consumption divided relatively evenly between developing countries and the EE/FSU regions. Energy use in residential buildings is about twice that of commercial buildings world-

Table 5-1 World Primary Energy Use in Buildings by Region.
Source: IEA, 1994a; British Petroleum, 1994b.

Region and	1971		1980		1990		1992		
Sector	Mtoe	EJ	Mtoe	EJ	Mtoe	EJ	Mtoe	EJ	Avg. Annual Growth Rate (%) 1971-1992
OECD*									
Residential	676	28.3	783	32.8	872	36.5	909	38.0	1.4
Commercial	351	14.7	464	19.4	586	24.5	609	25.5	2.6
Total Buildings	1027	43.0	1248	52.2	1458	61.0	1517	63.5	1.9
Developing Countries*									
Residential	117	4.9	209	8.8	357	15.0	374	15.7	5.7
Commercial	32	1.3	51	2.1	100	4.2	124	5.2	6.7
Total Buildings	149	6.2	260	10.9	457	19.2	498	20.9	5.9
EE/FSU**									
Residential	193	8.1	307	12.9	360	15.1	306	12.8	2.2
Commercial	62	2.6	126	5.3	189	7.9	169	7.1	4.9
Total Buildings	255	10.7	433	18.2	549	23.0	475	19.9	3.0
World									
Residential	985	41.3	1300	54.4	1589	66.5	1589	66.5	2.3
Commercial	446	18.7	641	26.8	875	36.7	901	37.7	3.4
Total Buildings	1431	60.0	1941	81.2	2464	103.2	2490	104.2	2.7

*Data from IEA, 1994a. China consumption in 1971 estimated.
**Data from British Petroleum, 1994b, using sectoral shared based on Cooper and Schipper, 1991.

wide; however, energy demand in commercial buildings has grown about 50% more rapidly than demand in residential buildings for the past two decades.

Some of the most important factors that drive energy consumption in buildings include population, economic growth, the type of energy services demanded, and the energy used to provide those services. For example, efficient building technologies such as energy-efficient lighting or air conditioning reduce the energy required to provide the same level of lighting or cooling desired. Some examples of efficient building technologies or practices are shown in Table 5-2.

Rapid increases in population growth will tend to drive up energy demand and the demand for particular energy services. Historical trends in energy demand are summarized by region.

Table 5-2 Energy-Efficient Technologies and Practices in Buildings.
Source: Levine et al., 1995.

Service	Technology
Space Conditioning	•Gas-fired, condensing furnaces •High-efficiency heat pumps •Air conditioning efficiency measures (e.g., thermal insulation, improved heat exchangers, advanced refrigerants, more efficient motors, etc.) •Centrifugal compressors, efficient fans and pumps, and variable air volume systems for large commercial buildings
Appliances	•Advanced compressors, evacuated panel insulation (refrigerators) •Use of horizontal axis technology (clothes washers) •Heat pump dryers
Cooking	•Improved efficiency of biomass stoves (developing countries)
Lighting	•Compact fluorescent lamps •Improved phosphors •Solid state electronic ballast technology •Advanced lighting control systems (including daylighting and occupancy sensors) •Task lighting
Motors	•Variable speed drives •Size optimization •Improvement of power quality •Use of synchronous and flat belts
Building Envelope	•Energy-efficient windows •Advanced insulation •Reduced air infiltration
Controls	•Building energy management systems

OECD Countries

Residential energy use in OECD countries grew 1.4% per year between 1971 and 1992. Population increases as well as decreases in the average number of persons per household caused energy use to increase. In addition, demand for various residential services, particularly for space heating, central air conditioning, water heating, and energy intensive appliances (refrigerators, color televisions, and clothes washers), has increased. At the same time, there has been a significant reduction in the energy required to deliver various services, particularly in technologies such as space heating furnaces, refrigerators, and lighting systems (Komor, 1995). New refrigerators in the U.S., for example, use about 40% of the energy of new refrigerators sold in the early 1970s. New and existing buildings in Scandinavian countries have greatly reduced heating energy.

Growth in energy use in OECD commercial buildings between 1971 and 1992 averaged 2.6% per year. There has been an increase in the demand for services or amenities (electricity for computers and office equipment, better lighting). Data for ten OECD countries show that electricity use increased at a rate of 2.2% per year from 1970 to 1990, due to increases in electric heating and computers and other office equipment (Schipper and Meyers, 1992). Both activity and the demand for more energy services have tended to drive up the demand for energy in the service sector. However, some of the increase in demand has been counteracted by improved insulation and more efficient lighting and other equipment.

Energy per unit of value added has declined in most OECD countries by 1 to 2% annually.

Developing Countries

Rapid economic growth and population increases in developing countries will bring with it large increases in energy consumption in all sectors of societies, including buildings, as countries rapidly expand their basic buildings infrastructure to service growing societies. From 1971 to 1992, purchased energy consumption for commercial and residential buildings in developing countries grew 6.7% per year and 5.7% per year respectively, slightly more than twice the world average. Per-capita energy consumption for buildings, particularly in Asia and Latin America, has grown faster than either population or GDP.

Table 5-3 Comparison of Saturation Levels for Major Appliances in Selected Developing Countries (%).

	Refrigerator	Color TV	Air Cond.	Clothes Washer
India	14-40[a]	17-38[a]	0-2[a]	8[b]
China[c]	18.5	30.2	0.7	34.3
Brazil[d]	66	35[e]	4	22
Mexico[f]	58	55[g]	6	42
Thailand[h]	63	117	18	22
Korea[i]	116	153	15	124

[a]Tyler et al., 1994 (based on 3 cities surveyed); [b]Sathaye and Tyler, 1991; [c]Sinton, 1995 (based on 1993 data) ; [d]Meyers et al., 1990; [e]Januzzi and Schipper, 1991 [f]Masera et al., 1993; [g]Friedmann, 1995; [h]Thailand Load Forecast Subcommittee, 1993; [i]Korea Energy Economics Institute, 1994.

Residential buildings in developing countries account for 78% of buildings energy consumption, and the share would be even higher if biomass energy were included. As developing country economies mature, the increasing urbanization and the substitution away from traditional fuels to commercial fuels will also increase purchased energy demand in buildings. Because of the strong correlation between income level and the ownership of appliances, demand for energy services such as refrigeration, home entertainment (television), and space conditioning will increase as economies expand.

Saturation levels of various appliances for selected developing countries are shown in Table 5-3, and a large potential exists for further adoption. A similar potential for expansion in the demand for services exists for commercial buildings. Energy-efficiency improvements have counteracted some of the increase in demand as shown by the examples of Korea and Brazil which reduced average refrigerator energy use by 5 to 10% annually during the 1980s. However, the sheer increase in population and demand for more energy services suggest that energy demand will continue to rise dramatically in the future.

Eastern Europe and the Former Soviet Union

From 1971 to 1988, building energy use in EE/FSU grew 4.7% per year, faster than OECD countries but more slowly than developing countries. Much of the building stock is in need of improvement and therefore requires the expenditure of significantly more energy to provide the same level of energy service as a similar building in OECD countries. For example, buildings in the FSU require 50% more energy to heat a square meter of floorspace (after correcting for weather) than buildings in the U.S. (Cooper and Schipper, 1991). In the residential sector, the largest end-uses are space-heating, water heating, and cooking. For commercial buildings, energy use per unit of floorspace can be double that of OECD countries as space conditioning systems are poorly regulated and the leakage from building envelopes is often high. Since 1988, the current economic restructuring has deflated energy demand. As EE/FSU economies recover, more persistent efforts will be needed to improve the efficiency of the building stock to avoid rapid increases in building energy demand.

6.0 Trends in Information Technology
6.0 Mouvements de la Technologie de l'Information

Overview

The development of information technology — as measured by advances in performance and reductions in cost — has been remarkable over the past two decades and will continue for the foreseeable future. The applications of information technology to energy use in industry and buildings has the potential to contribute to significant reductions in energy use in these sectors. The first of these observations is not surprising, and has been widely observed. The second is an emerging topic of importance to an assessment of energy use, but it is one that has been inadequately analyzed to date.

The progress in all areas of information technology (computer technology, communications systems, and display technology and input/output devices, etc.) has been significant. For computers, for example, central processing units have increased in speed 2000-fold in the past twenty years. Memory increased even more dramatically, from 1K bit chip in the 1970s to a 64M bit dynamic random today (i.e., by a factor of 64,000).

Expected achievements in the future will continue to revolutionize information technology. After the turn of the century, we can expect 1G bit memory elements, continued advances in computing speed and performance (through massively parallel computing and other techniques), powerful techniques for optical communication, the widespread application of micromachines (sensors or other machines that can, for example, be produced on a computer chip), and communication technology that relies on virtual reality devices, in which a physical, interactive environment can be simulated using information technology.

Examples of Applications of Electronics to Energy Savings

Lighting

The application of information technologies to lighting and motors, which account for about half of electricity demand in most countries, shows significant savings potential.

Electronics in the form of electronic ballasts has permitted lighting savings of 37% compared with typical fluorescent lamps of ten to fifteen years ago. Occupancy sensors can increase this to about 50%. The use of daylighting, also made possible by low-cost electronics in sensors and actuators, combined with electronic ballasts, can cut lighting energy use in perimeter areas by 70% from early 1980 levels. The effect of electronic ballasts in creating compact fluorescent lamps to replace incandescents is equally striking. Compact fluorescents, now produced and marketed throughout the world, consume 25 to 35% as much energy as an incandescent to produce the same light output.

Motors

Motors are the largest end-user of electricity in most countries throughout the world. Great opportunities for savings come from the use of variable speed drives on motors. For many applications, the need for power varies throughout the day or in different times during the year. Variable speed drives use electronic controls to modify the power input to the motor, allowing the speed of the rotor to be varied depending on the amount of motor power needed. The energy savings are highly dependent on specific applications. Studies have estimated electricity savings of 20 to 50% depending on the application (Nadel et. al, 1991).

Controls

These motors drive such machines as compressors, pumps, fans, and condensers. These latter machines are, in turn, components of other processes such as air conditioning, refrigeration, movement of fluids, people, or equipment. Virtually all of these processes are subject to feedback, feedforward, and control made possible through advanced electronics and information technology or through reduced costs of electronic components. For example, sensors can indicate precisely when air conditioning, ventilation air, or refrigeration are needed. They can also help to identify and reduce the factors that cause these loads. This application has the dual benefit of saving energy twice: once by reducing demand at the end-using equipment and secondly by increasing the benefit of the variable speed drive on the motor. Further savings will be made possible if sensors continue to decline in price and are much more widely used to indicate leaks, faulty insulation, poorly maintained equipment, etc.

Broader Issues

Information technology can changing disorder into order in entirely new ways. In analogy to the ability of living organisms to create order in their environment, information technology can provide information hitherto not available to reduce such waste as repeating unnecessary functions, carrying out useless activities, and producing goods that are not desired by consumers. The net effect is to substitute information for energy, in the sense that the accumulation and analysis of a sufficient volume of useful information can eliminate useless activities that would otherwise have consumed energy.

Up to a point, the larger the size of a system, the more efficient it becomes. However, when the size of a system passes a given point, its efficiency begins to fall again. In other words, there is a limit to economics of scale. One of the problems of large systems is that the center is not able to accommodate the diversity of its individual elements. In the case of mass production, consumers are often forced to purchase products that do not meet their individual tastes. In a sense, the market is glutted with a far larger quantity of products than are demanded.

While these broader topics may appear somewhat afield of the issue of energy demand in industry and buildings, they have important implications. If the dominant paradigm of our industrial society — mass production to provide the most products to the most people — gives way to a new paradigm in which demand drives production, then the very nature of the products demanded and the energy and other resources required by society can be changed. Furthermore, advances in communication technology, almost certain to take place in the coming decades, provide much more effective vehicles to convey to consumers the full consequences of their decisions.

Many of the concepts discussed in this section are described by the term “holonic system.” This concept, derived from ideas of cellular automata described by John van Neumann, was coined by Arthur Koestler in his book, *The Ghost in the Machine*. Koestler defines a holon as “a stable, integrated structure, equipped with self-regulatory devices and enjoying considerable degree of autonomy...” (Koestler, 1989). Discussion of these concepts among researchers in information technology, suggest relations between holonic systems — which can be applied to different levels of society, from the operation of institutions to manufacturing techniques to the energy system — and approaches to assure the sustainable evolution of society and its parts. One example is the concept of an “inverse factory” that takes the outputs of a traditional factory, after their use, and process them so that they can be used as inputs for the original factory. The design and use of products to be reprocessed in such an “inverse factory” requires distributed systems capable of both autonomy and harmony.

While we have not attempted to quantify the effects of such a change in paradigm for the consumption of society, they could be highly significant. The major impact of information technology over the long run may not be to simply make products more efficient, but to make the decision of what products to manufacture and the characteristics of these products more “efficient,” husbanding natural resources.

7.0 Scenarios
7.0 Scénarios

We developed three scenarios— business-as-usual, state-of-the-art, and ecologically driven/advanced technology — that approximate assumptions underlying three of the World Energy Council cases: B1 (modified reference), B (reference), and C (ecologically-driven), respectively (WEC, 1993). Results of our three scenarios for both the industrial and buildings sectors are shown in Figures 7-1 and 7-2.

Business-As-Usual Scenarios

Industrial Sector Energy Demand

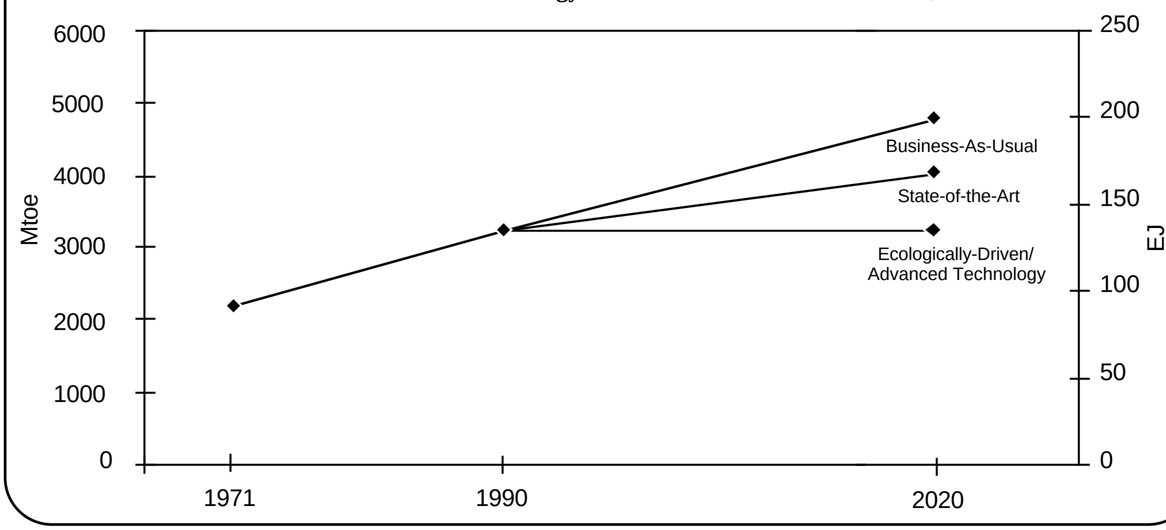
In the business-as-usual scenario, industrial energy demand grows from 3243 Mtoe (136 EJ) in 1990 to 4895 Mtoe (205 EJ) in 2020 at an average annual rate of 1.4%. This growth is slightly lower than the annual rate of 1.9% experienced between 1971 and 1992.

Industrial energy demand in the OECD region grew only 0.8% per year from 1971 to 1992. In the business-as-usual scenario, OECD industrial energy demand grows 0.6% per year from 1990 to 2020, with the chemicals and pulp and paper industries responsible for the increased growth. Energy intensity declines about 0.5 to 0.7% per year; thus, total industrial output grows about 1.2% per year over the period.

Industrial energy demand in the year 2020 is projected to be slightly lower than 1990 levels in the EE/FSU. This is largely due to a substantial decrease in energy consumption in iron and steel caused by a low growth rate in production in that subsector and increased energy efficiency. Petroleum refining shows the largest increase in energy consumption as the demand for oil and oil products grows. Industrial output of the energy-intensive industries increases by 1 to 1.5% per year (with the exception of iron and steel); however, energy efficiency gains compensate for much of this increased output.

Industrial output grows almost 4.0% per year in the developing countries, leading to energy growth of 3.1% per year from 1990 to 2020. This is a decline of annual industrial energy growth from 6.8% in the 1970s and 4.4% in the 1980s, as a result of a small decline in growth of industrial output and an increase in industrial energy efficiency.

Figure 7-1 Results of Business-As-Usual, State-of-the-Art, and Ecologically Driven/Advanced Technology Scenario for the Industrial Sector, 1990-2020.



Buildings Sector Energy Demand

In the business-as-usual scenario, energy demand in buildings (without agriculture) grows from 2464 Mtoe (103 EJ) in 1990 to 4959 Mtoe (208 EJ) in 2020, at an average annual growth rate of 2.4%. This is somewhat less than the historical growth rate of energy use in buildings of 3.0% experienced between 1971 and 1990. Energy use grows about 20% faster in commercial buildings than in residential.

Of the 2495 Mtoe (105 EJ) increase in energy use in buildings between 1990 and 2020, 502 Mtoe (21 EJ) is in the OECD, 1073 Mtoe (45 EJ) is in the EE/FSU, and 919 Mtoe (38 EJ) is in developing countries. The relatively higher energy growth in the EE/FSU results from a shift from a heavy industrial economy to a more consumer-based one in the EE/FSU, with considerable growth in the number and floor area of residential and commercial buildings in the region.

State-of-the-Art Scenarios

Industrial Sector Energy Demand

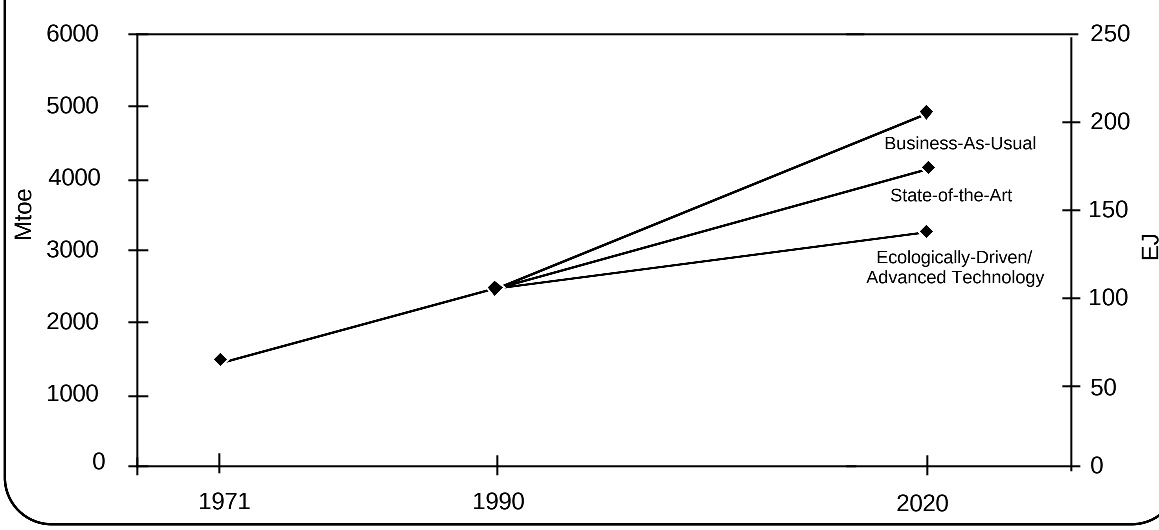
In the state-of-the-art scenario, industrial energy demand increases from 3243 Mtoe (136 EJ) in 1990 to 4119 Mtoe (173 EJ) in 2020, at an annual rate of 0.8%.

Industrial energy demand is essentially flat in the OECD, with a drop in iron and steel energy use and an increase in energy used in chemicals production. Industrial energy intensity declines 1.1 to 1.2% per year during the period. The greatest decline in industrial energy intensity is in chemicals production, at 1.45% per year; the smallest is in the pulp and paper industry, at 0.95% per year.

Industrial energy demand declines in the EE/FSU, largely because of low growth in steel production and significant reductions in energy intensity. Energy intensity in steel, chemicals, and cement production decline by about 1.5% per year, resulting in 2020 intensity levels just slightly below those of OECD countries in 1990.

Industrial energy demand in the developing countries grows by 2.5% per year. The energy intensity in developing countries in 2020 is equal to that of EE/FSU, even though most new industrial facilities in the developing countries are more efficient than those in the EE/FSU.

Figure 7-2 Results of Business-As-Usual, State-of-the-Art, and Ecologically Driven/Advanced Technology Scenario for the Buildings Sector, 1990-2020.



Total industrial energy growth in this scenario from 1990 to 2020 is 876 Mtoe (37 EJ). The decrease seen in the EE/FSU region of 365.4 Mtoe (15.3 EJ) is offset by the increase in the developing world of 1982 Mtoe (83 EJ) which is 118% of the total energy demand growth.

Buildings Sector Energy Demand

In the state-of-the-art scenario, energy demand in buildings increases from 2464 Mtoe (103 EJ) in 1990 to 4086 Mtoe (171 EJ) in 2020, at a rate of 1.7% per year. Average annual growth is 0.8% for OECD countries, 2.7% for EE/FSU, and 2.8% for developing countries. Overall, 41% of energy growth occurs in the EE/FSU, 36% in developing countries and 23% in the OECD.

Ecologically Driven/Advanced Technology Scenario

Industrial Sector Energy Demand

In the ecologically driven/advanced technology scenario, overall industrial energy demand in 2020 is virtually unchanged from 1990 levels, even assuming the same increase in industrial output as the business-as-usual and state-of-the-art scenarios. Industrial energy intensity declines about 1.5% per year in the OECD and about 2.2% per year for the developing countries and the EE/FSU. The greatest declines in industrial energy intensity in the developing world and the EE/FSU are in the chemicals industry (3.0% per year in the developing countries and 2.2% per year in the EE/FSU) and the cement industry (2.8% per year in both regions). Energy use in industry declines in the OECD by 176 Mtoe (7.4 EJ) and in the EE/FSU by 320 Mtoe (13.4 EJ) from 1990 to 2020. The increase in the developing world is 566 Mtoe (23.7 EJ).

Buildings Sector Energy Demand

In the ecologically driven/advanced technology scenario, world energy demand in buildings grows at a rate of 1.0% per year. Annual growth rates are 0.4% for OECD, 1.7% for EE/FSU, and 1.8% for developing countries. These growth rates, combined with 1990 levels of energy use in the three regions, leads to an increase in the proportion of world (purchased or commercial) energy use in buildings growing from 18.5% in 1990 to 23.5% in 2020 in developing countries. The share in the OECD drops from 59% in 1990 to 49% in 2020.

Total Energy Use in Industry and Buildings

The business-as-usual scenario projects an increase in total energy in industry and buildings from 5707 Mtoe (239 EJ) in 1990 to 9853 Mtoe (413) in 2020, corresponding to an average annual increase of 1.8%. The WEC case B1 (modified reference case), which includes industry, buildings and transport, projects an energy demand increase of 2% per year from 1990 to 2020. The state-of-the-art scenario projects total energy in industry and buildings increasing at an average annual rate of 1.2%, compared with the WEC reference case (which includes transport) of 1.4% over the period 1990 to 2020. The ecologically driven/advanced technology scenario projects energy demand increasing 0.5% per year, compared with the comparable WEC case (including transport) of 0.84% per year.

As our scenarios demonstrate, without significant efforts to promote energy efficiency, global energy use for the industrial and buildings sectors is projected to double by 2020. Only the most aggressive measures, along the lines of the ecologically driven/advanced technology scenario, are likely to hold future energy consumption at close to today's levels. These findings reinforce earlier WEC findings in *Energy for Tomorrow's World*.

8.0 Acknowledgments
8.0 Remerciements

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ENDNOTES

[1] Converting the end-use of energy into its primary equivalent is a difficult accounting task since each country has a different fuel mix which is transformed, transported, and consumed. Many of the energy consumption statistics cited in the study are based on end-use consumption statistics collected by the International Energy Agency (IEA). We have assigned an average approximation for the conversion of electricity. We use a conversion factor for primary energy into electricity of 3.1 for OECD countries and 3.5 for non-OECD countries.

Such an approximation inaccurately reflects the situation of many individual countries. Also, the assignment of one conversion factor for the whole time period of the study does not capture improvements of generation efficiency. In future analyses, we intend to modify this assumption, and include the effects of efficiency improvements in electricity generation.

[2] A joule is the heat equivalent of the application of one newton of force for a distance of one meter (ASTM, 1992).We express the energy used in a country in peta (10^{15}) or exa (10^{18})-joules, while physical energy intensities are expressed in gigajoules (10^9) per unit of output. Million tonnes of oil equivalent (Mtoe) is another common international energy unit; one exajoule equals 23.88 Mtoe.

[3] Value added is the value of sectoral production minus purchased material inputs.

[4] LHV is the energy content of gas and is equal to 31.7 MJ/m^3 for Groningen (Dutch) natural gas. (Worrell et al., 1994b)

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